

## METHOD OF PRODUCING CHIP THERMISTOR

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10           This is a continuation-in-part of application Serial No. 10/006,258 filed December 4, 2001, now pending, which is a divisional of application Serial No. 09/712,388 filed November 13, 2000 now U.S. patent 6,362,723 issued March 26, 2002.

### Background of the Invention

15           This invention relates to a method of producing chip thermistors and more particularly to composite electronic devices including a resistor and a chip.

          Surface-mountable chip thermistors are coming to be widely used in recent years. As is well known, chip thermistors include both the PTC type and the NTC type, and the B-constant (the resistance-temperature characteristic) of an NTC thermistor is determined by  
20   the composition of the thermistor ceramic material to be used and has been difficult to control freely. For this reason, it has been a common practice to connect a resistor in series or in parallel with a thermistor to adjust the B-constant for each circuit to be used. This not only adversely affects the workability but also requires a larger area to individually mount a resistor and a thermistor to a circuit board as individual electronic components.

25           In view of the above, Japanese Patent Publication Tokkai 64-1206 has disclosed a chip thermistor having a resistor layer formed between outer electrodes on its outer surface such that the thermistor and the resistor layer are connected in parallel. This has the advantage in that the area for the surface mounting can be reduced because the thermistor and the resistor are on a single chip and also in that the B-constant of the thermistor can be  
30   freely adjusted by varying the resistance of the resistor layer.

          Chip thermistors thus structured, however, have a lower reliability because the resistor layer is externally exposed. In addition, errors are likely to be committed in their mounting, that is, they are likely to be mounted erroneously with the resistor layer on the side of the circuit board.

### Summary of the Invention

It is therefore an object of this invention to provide a method of producing a compact and reliable chip thermistor of which the B-constant can be adjusted easily and errors in mounting can be obviated.

A chip thermistor embodying this invention, with which the above and other objects can be accomplished, may be characterized as comprising a main body of a thermistor ceramic material having a specified resistance-temperature characteristic, outer electrodes formed on its outer end surfaces, at least one high-resistance conductor (or a "resistor") and inner electrodes inside the thermistor ceramic body and wherein the resistor and at least one mutually separated pair of inner electrodes with the thermistor ceramic material in between are electrically connected either in series or in parallel. Since a thermistor and a resistor are made into one chip according to this invention, it is possible to obtain a chip thermistor which is compact and of which the B-constant can be freely adjusted. Since the resistors are not externally exposed but are formed inside the thermistor ceramic, there is no danger of their erroneously contacting an external circuit at the time of mounting the chip thermistor. In other words, it is only the outer electrodes that are externally exposed, and this improves reliability. For the purpose of the present invention, the expression "high-resistance conductor" or "resistor" is defined as an electronic element with a much higher resistance than the inner electrodes, or an element with resistance greater than  $1\Omega$ , the resistance of the inner electrode being typically in the milliohm range.

The resistance value of the high-resistance conductors can be freely changed by connecting in series and/or parallel the inner electrodes facing each other and sandwiching the thermistor ceramic material in between. In order to obtain a larger resistance value, the resistors may be formed in the shape of a coil. This method is preferable because it is possible to increase the resistance value without being affected by the thermistor characteristic between the conductors.

Thermistors with negative thermistor-resistance characteristics (NTC thermistors) are widely in use for temperature compensation for a circuit element and temperature detection. The B-constant of such an NTC thermistor is determined by the material composition of the thermistor ceramics. The B-constant represents the magnitude of change

in no-load resistance value against temperature and may be obtained from two arbitrary temperatures T and T<sub>0</sub> as follows:

$$B = \{\log \{R/R_0\}\} / \{(1/T)-(1/T_0)\} \quad \text{Formula (1)}$$

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where T and T<sub>0</sub> are in units of absolute temperature (K) and R and R<sub>0</sub> are no-load temperature values at these temperatures in  $\Omega$ . Since the ratio R/R<sub>0</sub> changes, the B-constant can be changed although the thermistor ceramics are the same.

According to a preferred method of producing such a chip thermistor, green sheets  
10 containing a NTC thermistor ceramic material having the property of becoming a thermistor ceramic by a firing process and an organic binder are prepared, and a resistor paste is applied on one or more of these green sheets, while an inner electrode paste is applied on some others of the green sheets. In the above, "resistor paste" is the expression to be used herein for a paste having the property of becoming a resistor within the meaning of this  
15 invention defined above when subjected to a firing process, and "inner electrode paste" is the expression for a paste having the property of becoming an inner electrode when subjected to the firing process. A layered structure free of PTC materials is formed by stacking and compressing together specified numbers of the green sheets and after it is subjected to a firing process. Outer electrodes are formed on mutually opposite end surfaces  
20 of this layered structure. This method is advantageous in that the green sheets with nothing applied thereon and those printed with a paste are subjected to a firing process all at once. In other words, the production process involves fewer steps and this affects the production cost favorably. The resistance value of the resistor can be varied easily by adjusting the number of green sheets with resistors printed thereon to be stacked in the layered structure.

25 The inner electrodes and the resistor can be connected in series merely by connecting the ends of the resistor and the inner electrodes to corresponding ones of the outer electrodes. When they are to be connected in series, the resistor and the inner electrodes must be electrically connected inside the ceramic main body. This may be accomplished by producing a throughhole inside the thermistor ceramic and filling the throughhole with a  
30 conductor material. This method can be applied also for forming the resistor in the shape of a coil.

### Brief Description of the Drawings

The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiments of the invention and, together with the description,  
5 serve to explain the principles of the invention. In the drawings:

Fig. 1 is a sectional view of a chip thermistor according to a first embodiment of this invention;

Fig. 2 is a sectional view taken along line 2-2 of Fig. 1;

Fig. 3 is a sectional view taken along line 3-3 of Fig. 1;

10 Fig. 4 is an equivalent circuit diagram of the chip thermistor of Fig. 1;

Fig. 5 is an exploded diagonal view of the chip thermistor of Fig. 1 for showing its layer structure;

Fig. 6A is a sectional side view of another chip thermistor according to a second embodiment of this invention taken along line 6A-6A of Fig. 6B, and Fig. 6B is a sectional  
15 view taken along line 6B-6B of Fig. 6A;

Fig. 7 is an exploded diagonal view of the chip thermistor of Fig. 6 for showing its layer structure;

Fig. 8A is a sectional side view of still another chip thermistor according to a third embodiment of this invention taken along line 8A-8A of Fig. 8B, and Fig. 8B is a sectional  
20 view taken along line 8B-8B of Fig. 8A;

Fig. 9 is an equivalent circuit diagram of the chip thermistor of Fig. 8;

Fig. 10A is a sectional side view of still another chip thermistor according to a fourth embodiment of this invention taken along line 10A-10A of Fig. 10B, and Fig. 10B is a sectional view taken along line 10B-10B of Fig. 10A; and

25 Fig. 11 is an equivalent circuit diagram of the chip thermistor of Fig. 10.

Throughout herein, components which are equivalent or similar are indicated by the same numerals even where they are components of different chip thermistors and may not necessarily be described or explained repetitiously.

### 30 Detailed Description of the Invention

The invention is described next by way of examples. Fig. 1 shows a chip thermistor according to a first embodiment of this invention characterized as having planar elongated resistors 3 with resistance  $1\Omega$  or greater as shown in Fig. 2 and a plurality of planar elongated inner electrodes (first inner electrodes 5a and second inner electrodes 5b) extending in mutually opposite directions formed inside a ceramic body 1 made of a thermistor material with a desired resistance-temperature characteristic. Explained more in detail, the ceramic body 1 is planar, having an upper surface and a lower surface which are parallel and facing away from each other and extending between two mutually oppositely facing end surfaces. Both ends of each of the resistors 3 are exposed to the exterior on these end surfaces of the ceramic body 1. One end of each of the first inner electrodes 5a is exposed on one of the end surfaces, and one end of each of the second inner electrodes 5b is exposed on the other of the end surfaces of the ceramic body 1. Outer electrodes (the first outer electrode 6 and the second outer electrode 7) are formed each on corresponding one of the end surfaces of the ceramic body 1 such that one end of each of the resistors 3 and the exposed ends of the first inner electrodes 5a are electrically connected to the first outer electrode 6, while the other end of each of the resistors 3 and the exposed ends of the second inner electrodes 5b are electrically connected to the second outer electrode 7. Thus, the thermistor characteristic between the first and second inner electrodes 5a and 5b and the resistors 3 are connected in parallel through the outer electrodes 6 and 7, and its equivalent circuit diagram becomes as shown in Fig. 4.

As shown in Fig. 5, a specified number of ceramic layers 8 with a ceramic body 1 and a resistor 3 thereon which is elongated like a belt and narrower than the ceramic body 1 are stacked one above another, and cover sheets 9 each comprising one or more ceramic layers having no resistor thereon are placed below and above this stacked structure. Furthermore, several ceramic layers 10 each having a first inner electrode 5a or a second inner electrode 5b extending from a middle position to one or the other of the edge parts are stacked one above another such that the first and second inner electrodes 5a and 5b overlap partially, as seen perpendicularly to the layers. Another cover sheet 9 comprising one or more ceramic sheets having no electrode formed thereon is placed below the lowest of the ceramic layers 10 to form a composite layered structure. A chip thermistor is formed by forming outer electrodes 6 and 7 over the mutually oppositely facing end surfaces of this

composite layered structure at which the resistors and the inner electrodes 5a and 5b are externally exposed.

A method by which such a chip thermistor was produced will be explained next. First, oxides of Mn, Ni and Co were mixed at a ratio of 52:12:32 (in wt %) and after the  
5 mixture was pre-baked, green sheets were produced by adding an organic binder, water, a dispersant and a surfactant and molding it in a sheet form. Sheets of a specified size were punched out from this green sheet and they were printed upon with an inner electrode paste which was a mixture of PdO and Pd at weight ratio of 10:0 - 50:50 and an inner electrode paste which was a mixture of Pd and Ag at weight ratio of 70:30. They were then stacked  
10 and compressed together.

A plurality of unit cells were formed on each green sheet. After the layers were stacked and compressed, as explained above, the stacked structure was cut appropriately and individual chip bodies were obtained. These chip bodies were then subjected to a firing process to obtain fired units. After surfaces of each fired unit were polished to expose the  
15 resistors 3 and the inner electrodes 5a and 5b, outer electrodes 6 and 7 were formed. The outer electrodes 6 and 7 may be formed by any of the known conventional methods such as firing of Ag, plating (Ni-Sn, Ni-Sn-Sn/Pb) and sputtering (monel-Ag-solder, Ag-solder). Although a parallel connection as shown in Fig. 1 of resistors and inner electrodes through outer electrodes was used to form an equivalent of a circuit shown in Fig. 4, they may be  
20 preliminarily connected through a throughhole inside the thermistor ceramic and then pulled out to the end surface to be connected to the outer electrodes.

Table 1 shows the overall resistance and overall B-constants of NTC thermistor single bodies ( $300\Omega$  and  $100\Omega$ ) and composites with a resistor and an NTC thermistor as shown in Fig. 1. The dimensions of the unit were 2mm in length, 1.20mm in width and  
25 0.9mm in thickness and the width of the belt-like resistor was 0.8mm.

Examples of thermistor material for forming the green sheets include oxides of Mn, Ni, Co, Cu, Al and Fe. Materials for the resistor include PdO, Pd,  $\text{Lu}_2\text{O}_3$ , SiC and their mixtures. Examples for inner electrode paste include Ag, Ag-Pd, Pt and Pb. It is to be noted that the layers 8 shown in Fig. 5 include only NTC thermistor materials, no PTC  
30 thermistor materials being included.

Table 2 shows the resistance value of each of resistors 3 with length 2mm, width 0.8mm and thickness 0.001-0.1mm, as shown in Fig. 1, produced with different materials.

Table 1

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0:100	1	1000	300	3450	230.77	109.61	2869
25:75	1	500	300	3450	187.50	98.78	2470
25:75	2	250	300	3450	136.36	82.49	1937
40:60	1	125	300	3450	88.24	62.02	1359
0:100	1	1000	100	3450	90.91	39.42	3220
25:75	1	500	100	3450	83.33	37.92	3034
25:75	2	250	100	3450	71.43	35.25	2722
40:60	1	125	100	3450	55.56	30.89	2262
40:60	2	62.5	100	3450	38.46	24.77	1696

In Table 1:

- (1) Ratio of PdO within resistor or Pd:PdO;
- (2) Number of resistors;
- (3) Resistance of resistor ( $\Omega$ );Pd:PdO Pd:PdO
- 10 (4) Resistance of NTC ( $\Omega$ );
- (5) B-constant of NTC (K);
- (6) Overall resistance at 25°C ( $\Omega$ );
- (7) Overall resistance at 50°C ( $\Omega$ );
- 15 (8) Overall B constant b25/50 (K).

Table 2

Material	Content in Paste	Resistance ( $\Omega$ )
Pd:PdO	0:100	100
Pd:PdO	10:90	700
Pd:PdO	25:75	500
Pd:PdO	40:60	125
Pd:PdO	50:50	10
Pd:PdO	75:25	5
Pd:PdO	90:10	2
Pd:Cu	25:75	2500
Pd:Ni	25:75	
Pd:SiC	25:75	200
Ni	100	30k
Cr	100	150k
SiC	100	1500
Pd: Strontium titanate	25:75	700
Pd: Barium titanate	25:75	3000

Materials shown in Fig. 2 were each used to produce a paste by mixing a solid component by 70 weight %, a resin component by 23 weight % and a solvent by 7 weight %. Each paste was applied by a screen printing method by selecting the viscosity of the paste and the kind of printing screen such that the thickness of the prints after drying would be 10-100 $\mu$ m. The firing process was carried out for 1-5 hours at 1000-1250°C and by cooling at 200°C. Although PdO does not possess electrical conductivity, it is reduced during the firing process such that a portion thereof becomes metallic Pd and becomes electrically conductive. Thus, a resistor can be obtained even by using a paste containing only PdO but its resistance value can be more easily controlled by using a mixture of Pd and PdO as paste. In the case of Ni, Cr or Cu, a portion may oxidize, depending on the conditions of the firing process and the oxygen density, generating oxides such as NiO, Cr<sub>2</sub>O<sub>3</sub> and CuO and thereby attaining a significantly high resistance value. The resistance value can further be controlled by mixing Pd. With SiC, strontium titanate and barium titanate, the elements in the thermistor are diffused to cause large changes in the resistance value. Mn and Fe, in particular, respond sensitively and increase the resistance value.



Table 1 shows clearly that the B-constant of a thermistor single body (3450K) can be varied significantly by varying the resistance of the resistor 3. Although the B-constant obtainable with a thermistor material is usually in the range of 2500K-4500K, it was possible by making a composite with a resistor to obtain a low B-constant value such as 1359K which could not be obtained before. Since the resistance value can be changed at will by varying the shape, the number of layers and the material of the resistor 3, the B-constant value can accordingly be varied to a large extent. Depending on the combination of the resistance of the material for the resistor and the resistance of the NTC thermistor, the B-constant can be made as small as the temperature coefficient of the resistor.

Figs. 6A, 6B and 7 show another chip thermistor according to a second embodiment of the invention, characterized in that resistors 3 are formed in the shape of a coil connected in parallel with the inner electrodes 5a and 5b. As shown in Fig. 7, a plurality of ceramic layers 8 each having an L-shaped resistor 3 formed on the upper surface are stacked and these resistors 3 on different ceramic layers 8 are connected through conductors buried in throughholes 11 such that a spiraling coil is formed. For forming the resistors 3 in the shape of such a coil, the resistors 3 on only the top and bottom of these plurality of ceramic layers 8 extend to one of the edges (as indicated by 3a and 3b) to be connected to the outer electrodes 6 and 7. In this example, too, the shapes of the resistors high-resistance conductors 3 and the number of the ceramic layers 8 are determined according to the target resistance for the chip thermistor. The inner electrodes 5a and 5b and the cover sheets 9 are as explained above with reference to the first embodiment of the invention shown in Fig. 5.

This embodiment is advantageous in that higher resistance values can be obtained than the first embodiment of the invention because the resistors 3 are formed in the shape of a coil. A higher resistance value can be otherwise obtained, for example, by forming the resistors 3 in a zigzag pattern or by reducing the width but resistive conductors with an excessively small width are likely to become broken and a zigzag pattern tends to cause a short circuiting if the separation between zigzagging lines is made too small. By forming the resistors 3 in the shape of a coil, it is possible to increase the resistance value without causing any line breakage or short circuiting.

Figs. 8A and 8B show still another chip thermistor according to a third embodiment of the invention, and Fig. 9 is its equivalent circuit diagram. This example is similar to the

second embodiment of the invention in that the resistors 3 are formed in the shape of a coil but different therefrom in that the resistors 3 and the inner electrodes 5a and 5b are connected in series. In other words, one end 3a of one resistor 3 is connected to the first outer electrode 6, the other end 3b is connected to the first inner electrodes 5a and the second inner electrode 5b is connected to the second outer electrode 7. The first inner electrodes 5a not contacting the first outer electrode 6, it should be clear from Figs. 8A and 8B that an equivalent circuit diagram for this chip thermistor is as shown in Fig. 9. As should be clear from Formula (1) above, the ratio  $R/R_0$  can be varied in this example by connecting the resistors 3 in series with the inner electrodes 5a and 5b and hence the B-constant can be adjusted.

Figs. 10A and 10B show still another chip thermistor according to a fourth embodiment of this invention, and Fig. 11 is its equivalent circuit diagram. This embodiment is different from the third embodiment explained above with reference to Figs. 8A, 8B and 9 in that there is an additional resistor 3' provided inside the ceramic body 1 with one of its ends contacting the first outer electrode 6 and the other of its ends contacting the second outer electrode 7. In other words, this additional resistor 3' is connected in parallel with the aforementioned series connection of the resistors 3 and the inner electrodes 5a and 5b. Thus, the equivalent circuit diagram of this chip thermistor is as shown in Fig. 11. It now goes without saying that chip thermistors according to the fourth embodiment of the invention have the characteristics of chip thermistors according to both the first and the third embodiments of the invention.

Although the invention has been described with reference to only a limited number of embodiments, these embodiments are not intended to limit the scope of the invention. Although only embodiments having no more than one series or parallel connection were illustrated above, connections may be provided between a plurality of series and/or parallel connections. Although the invention was described by way of examples using NTC thermistors, it is also possible to use PTC thermistors. If PTC thermistors are used, the resistance increases as the temperature is increased but the manner in which the resistance increases (or the increase characteristic) can be varied by connecting resistors in series or parallel. PTC materials which may be used for producing chip thermistors of this invention may be obtained, for example, by adding oxide of yttrium, Mn or Pb to barium titanate.

Although a production method wherein layers of different kinds are stacked together and then subjected to a firing process, these layers may be individually subjected to a firing process and then pasted together by using, for example, a glass paste comprising lead borosilicate. The stacked composite structure thus obtained is thereafter cut to a desired  
5 chip size to obtain individual chip bodies.

When a plurality of green sheets with an inner electrode formed thereon are stacked and then subjected to a firing process, electric charge of the material for the electrodes may shift to the ceramic material to thereby generate a voltage difference. This may produce a barrier layer serving as an electrical wall to make it difficult to attain the desired resistance.  
10 In order to obviate problems of this nature, it may be preferable to form inner electrodes on ceramic plates which have already been subjected to a firing process and to stack and paste them together through a resistor layer.

Although examples were shown wherein the inner electrodes 5a and 5b are arranged so as to overlap as seen perpendicularly to their planes, this is not intended to limit the scope  
15 of the invention. These inner electrodes 5a and 5b may be coplanar, facing each other with a gap in between on the same plane or they may be arranged in a step-wise relationship, although not separately illustrated.

In summary, the disclosure is intended to be interpreted broadly and all modifications and variations of the disclosed examples that may be apparent to a person  
20 skilled in the art are intended to be within the scope of this invention.